AUDIT REPORT
ANALYSIS AND CALCULATIONS IN SUPPORT OF THE RESOLUTION OF BULLETIN 2012-01, "DESIGN VULNERABILITY IN ELECTRIC POWER SYSTEM"

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1.0 SUMMARY

On June 2 – 3, 2014, the U.S. Nuclear Regulatory Commission (NRC) conducted an audit at the Westinghouse Twinbrook office in Rockville, Maryland. The audit was conducted to verify that the responses to Request for Additional Information (RAI) 08.02-25 and RAI 08.02-26 are supported by the analysis and other supporting documentation developed by Nuclear Innovation North America, LLC. (NINA) to address the issues described in Bulletin 2012-01, "Design Vulnerability in Electric Power System" (ML12074A115).

This audit follows the guidelines in Office of New Reactors (NRO) Office Instruction NRO-REG-108 (Revision 0), "Regulatory Audits."

2.0 BACKGROUND AND AUDIT BASES

On July 27, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued Bulletin 2012-01, "Design Vulnerability in Electric Power System" (ML12074A115). The NRC staff issued RAI 08.02-25 and RAI 08.02-26 requesting NINA to address the issues described in the bulletin. NINA provided its initial responses to these RAIs at various times in 2013 and 2014. The NRC staff found these responses unacceptable. On May 15, 2014, NINA re-issued and superseded previous responses. The NRC staff identified a need to audit the analyses in support of the revised responses submitted in May 15, 2014.

3.0 OBJECTIVES

The objectives of the staff's audit were to:

- Observe the simulations of the ETAP 345 kV Transformer Open Phase Study as they pertain to the responses to RAI 08.02-25 and RAI 08.02-26.

- Review the assumptions, calculations, and conclusions of the Negative Sequence Relay Setting Calculation as they pertain to the responses to RAI 08.02-25 and RAI 08.02-26.

4.0 OBSERVATIONS AND RESULTS

The audit focused on the following areas: ETAP 345 kV Transformer Open Phase Study and Negative Sequence Relay Setting Calculation.

Description of the STP, Units 3 and 4, Electrical Distribution System:

The STP, Units 3 and 4, onsite and offsite electrical power system design includes three separate offsite power supplies for each unit. The three offsite power supplies are connected to the onsite power distribution system via three transformers - a Main Power Transformer (MPT) and two Reserve Auxiliary Transformers, RAT-A and RAT-B. During power operation the main generator output is sent to the offsite grid via the MPT and a portion of the output supplies three unit auxiliary transformers (UATs) which in turn supply two Class 1E 4.16 kV busses. Since each unit has a main generator circuit breaker, on a main generator trip, the UATs and the two Class 1E 4.16 kV busses are automatically back fed from the offsite grid via the MPT. The third Class 1E 4.16 kV bus is normally supplied by RAT-B. RAT-A is connected to the offsite grid in a standby mode and can be readily aligned from the Main Control Room to supply all three of the Class 1E 4.16 kV busses. The STP, Units 3 and 4, electrical distribution system does not utilize any automatic bus transfer schemes.

As per General Design Criteria (GDC) 17, STP, Units 3 and 4, is required to have two qualified offsite circuits between the offsite transmission network and the onsite Class 1E distribution system to be operable at all times, with one of the two sources required to be the MPT. Each offsite circuit consists of all breakers, transformers, switches, interrupting devices, cabling, controls, and control power supplies required to transmit power to the onsite Class 1E 4.16 kV busses.

Each of the Class 1E 4.16 kV busses has its own Emergency Diesel Generator (EDG). In addition, the STP, Units 3 and 4, design also includes a Combustion Turbine Generator (CTG) that can supply any two of the three Class 1E 4.16 kV busses. In the STP, Units 3 and 4, design, all three sources of offsite power, all three diesels, and the CTG would have to fail before a unit would lose the ability to power at least one of the Class 1E 4.16 kV busses.

Study: ETAP 345 kV Transformer Open Phase Study

The ETAP 345 kV Transformer Open Phase Study was performed to demonstrate how the STP, Units 3 and 4, electrical system would respond to an open phase condition and to determine the expected safety bus trips, alarms and operator actions. These simulations were performed using the Electrical Transient Analysis Program (ETAP) Version 12.5. Several simulations were performed for the following open phase scenarios:

- Open phase on the high side of the Main Power Transformer (MPT), Reserve Auxiliary Transformer RAT-A, or Reserve Auxiliary Transformer RAT-B.

- Open phase with the Main Generator online and offline.
- Open phase with heavily and lightly loaded Class 1E 4.16 kV busses.

NINA presented the assumptions, simulations, and conclusions to the staff. A summary description of some of the scenarios, including the operator response and the results of the ETAP calculated voltages, is provided below.

Case #1: Generator On-line – Power Operation

Open Phase on MPT

When the plant is at power, the main generator normally supplies two of the Class 1E 4.16 kV busses (Divisions I and II) via the unit auxiliary transformers, and RAT-B supplies the third Class 1E bus (Division III) from the offsite grid. RAT-A is connected to the offsite grid but is unloaded in a standby mode. In this configuration, the MPT is transmitting power to the offsite grid. When an open phase occurs on the high side of the MPT, the Division I and II busses supplied by the main generator will experience a negative sequence voltage greater than 4.5 percent. The negative sequence relay actuation will initiate action that will result in a transfer of the busses to their respective EDG. The Class 1E 4.16 kV bus being supplied by RAT-B will experience a small negative sequence voltage because the generator is trying to transmit the power through two phases. This negative sequence voltage will be less than the setpoint, and the bus will continue to be powered from its offsite source. All three busses remain powered by an offsite circuit or an EDG throughout the event.

Two cases were analyzed using ETAP, one case for lightly loaded Class 1E 4.16 kV busses and one for heavily loaded busses. In this context, a heavily loaded bus is greater than 5 MW (typical of accident loads) and a lightly loaded bus is less than 0.5 MW. In performing these simulations, the open phase is always simulated on Phase A. In the following tables V_{AB} is the phase-to-phase voltage between phases A and B, which is the voltage seen by the relay. Also, prior to the open phase, the negative sequence voltage for each bus is 0 percent and divisional phase-to-phase voltages for all three divisions are 100 percent. The negative sequence voltage is the vector summation of the phase-to-phase voltages V_{AB}, V_{BC}, and V_{CA}. In both simulation cases, the Division I and II busses actuate on negative sequence voltage. The negative sequence voltages are greater than 7.5 percent compared to the expected nominal relay setpoint of 4.5 percent. The negative sequence voltage is greater than 4.5 percent for several minutes until the main generator trips. The Division III bus does not actuate, with a maximum negative sequence voltage of 2.0 percent. The ultra-violet (UV) relays do not actuate in these scenarios until the negative sequence relay actuates and opens the bus feeder breaker.

The automatic actions, operator actions and the ETAP results are shown in the following tables.

Generator On-line – Power Operation Open Phase on MPT
Automatic Actions
Open phase on the high voltage side of the MPT (Phase A)
Open phase alarms in Main Control Room
Division I and II Class 1E 4.16 kV busses experience a negative sequence voltage > 4.5%
After a 2.5 second time delay, the negative sequence relay opens the feeder breakers to the Division I and II 4.16 kV busses
Division I and II busses reach undervoltage (UV) setpoint
After a 3 second time delay, EDGs on Division I and II start
When EDGs reach full speed, the Loss Of Off-site Power (LOOP) sequencer connects the appropriate Division I and II loads onto their EDG
Operator Actions
Based on the open phase alarm, operators start to implement their response procedure
Once the open phase alarm is confirmed, the operators enter TS 3.8, Electrical Power Systems
The procedure guides operators to transfer the Class 1E 4.16 kV busses to an unaffected source of offsite power
Once the transfer is successful, the EDGs are secured and TS 3.8 Limiting Condition for Operation (LCO) is exited
Troubleshooting and maintenance take place on the MPT open phase

Generator On-line – Power Operation Open Phase on MPT		
Case	1	2
Loading of 4.16 kV busses affected by open phase	Light	Heavy
Div 1 Negative Sequence Voltage [%]	8.7	7.7
Div 1 Bus V_{AB} [%]	99.2	99.3
Div 1 Bus V_{BC} [%]	113.0	111.7
Div 1 Bus V_{CA} [%]	101.8	101.9
Div 2 Negative Sequence Voltage [%]	9.4	7.8
Div 2 Bus V_{AB} [%]	98.5	99.5
Div 2 Bus V_{BC} [%]	113.5	112.1
Div 2 Bus V_{CA} [%]	101.3	102.1
Div 3 Negative Sequence Voltage [%]	2.0	2.0
Div 3 Bus V_{AB} [%]	98.5	98.5
Div 3 Bus V_{BC} [%]	100.5	100.5
Div 3 Bus V_{CA} [%]	102.0	102.0

Case #2: Generator Online – Power Operation

Open Phase on RAT-A or RAT-B

If an open phase condition occurs on RAT-B (normal plant lineup) while the plant is at power, the negative sequence relay on Division III would actuate and initiate actions that will result in a transfer of the Division III bus to the EDG. There is no significant impact on Divisions I and II which will continue to be supplied by the main generator.

If the open phase occurs on the high side of RAT-A, there is no immediate impact because this transformer is not normally aligned to supply any of the Class 1E 4.16 kV busses and is unloaded. However, the open phase detection system on RAT-A would detect and alarm in the

Main Control Room and operators would dispatch maintenance to address this inoperable offsite power supply. Since there are two operable offsite sources, there would be no actions required by the Technical Specifications.

If RAT-A is aligned to the Division III Class 1E 4.16 kV bus and experiences an open phase, the response results would be identical to the system response described for RAT-B above.

The automatic actions, operator actions and the ETAP results are shown in the following tables for an open phase on RAT-B. The results are provided for a heavily and lightly loaded Division III Class 1E 4.16 kV bus.

Generator Online – Power Operation Open Phase on RAT-B
Automatic Actions
Open phase on the high voltage side of the RAT-B (Phase A)
Open phase alarms in Main Control Room
Division III Class 1E 4.16 kV bus experiences a negative sequence voltage > 4.5%
After a 2.5 second time delay, the feeder breaker to the Division III bus is opened
Division III bus reaches UV setpoint
After a 3 second time delay, EDG on Division III starts
When the EDG reaches full speed, the Loss Of Off-site Power (LOOP) sequencer connects the appropriate loads to the EDG
Operator Actions
Based on the open phase alarm, operators start to implement their response procedure
Once the open phase alarm is confirmed, the operators enter TS 3.8, Electrical Power Systems
Procedure guides operators to transfer the offsite power source to RAT-A
Once transfer is successful, the EDG is secured and TS 3.8 LCO is exited
Troubleshooting and maintenance take place on the RAT-B open phase

Generator On-line – Power Operation Open Phase on RAT-B		
Case	3	4
Loading of 4.16 kV bus affected by open phase	Light	Heavy
Div 1 Negative Sequence Voltage [%]	0.0	0.0
Div 1 Bus V_{AB} [%]	100.1	100.1
Div 1 Bus V_{BC} [%]	100.1	100.1
Div 1 Bus V_{CA} [%]	100.1	100.1
Div 2 Negative Sequence Voltage [%]	0.0	0.0
Div 2 Bus V_{AB} [%]	100.4	100.4
Div 2 Bus V_{BC} [%]	100.4	100.4
Div 2 Bus V_{CA} [%]	100.4	100.4
Div 3 Negative Sequence Voltage [%]	28.0	17.3
Div 3 Bus V_{AB} [%]	57.5	66.6
Div 3 Bus V_{BC} [%]	100.0	95.9
Div 3 Bus V_{CA} [%]	69.3	90.4

Case #3: Generator Offline, Backfeeding via MPT

Open Phase on MPT

When the main generator is offline, the Division I and II Class 1E 4.16 kV busses are back fed from the offsite grid via the MPT and UATs. If an open phase condition occurs on the high voltage side of the MPT, the two busses fed by this transformer would experience negative sequence voltages, but they would be less than the setpoint. For example, the maximum negative sequence voltage would be 2.2 percent, compared to the expected nominal setpoint of 4.5 percent. The phase-to-phase voltages would remain between 94 percent and 101 percent. The Division III Class 1E 4.16 kV bus supplied by RAT-B would experience a very small negative sequence voltage (<0.1 percent). None of the three busses would transfer to their

EDG because the negative sequence voltage on the busses is less than the setpoint of the negative sequence voltage relay. After receiving the Main Control Room alarm due to the open phase on the MPT, the operators would transfer the offsite power supply for Division I and II Class 1E 4.16 kV busses to another source of offsite power, RAT-A, and the appropriate TS would be applied. The actions necessary to perform this transfer can all be performed from the Main Control Room.

The results of the simulations for an open phase on the MPT with the plant shutdown are provided for a heavily and lightly loaded Division I and II Class 1E 4.16 kV busses. The automatic actions, operator actions and the ETAP results are shown in the following tables.

Generator Offline – Backfeeding via MPT Open Phase on MPT
Automatic Actions
Open phase on the high voltage side of the MPT
Open phase alarms in Main Control Room
Operator Actions
Based on the open phase alarm, operators start to implement their response procedure
Once the open phase alarm is confirmed, the operators enter TS 3.8, Electrical Power Systems
Division I and II Class 1E 4.16 kV busses are transferred from the MPT to RAT-A and TS 3.8 LCO is exited
Troubleshooting and maintenance take place on the MPT open phase

Generator Offline – Backfeeding via MPT Open Phase on MPT		
Case	5	6
Loading of 4.16 kV busses affected by open phase	Heavy	Light
Div 1 Negative Sequence Voltage [%]	2.1	0.7
Div 1 Bus V_{AB} [%]	97.9	99.8
Div 1 Bus V_{BC} [%]	95.0	99.1
Div 1 Bus V_{CA} [%]	98.5	100.2
Div 2 Negative Sequence Voltage [%]	2.2	0.7
Div 2 Bus V_{AB} [%]	97.7	99.8
Div 2 Bus V_{BC} [%]	94.7	99.1
Div 2 Bus V_{CA} [%]	98.2	100.3
Div 3 Negative Sequence Voltage [%]	0.0	0.0
Div 3 Bus V_{AB} [%]	100.4	100.3
Div 3 Bus V_{BC} [%]	100.3	100.3
Div 3 Bus V_{CA} [%]	100.3	100.3

Case #4: Generator Offline, Backfeeding via MPT

Open Phase on RAT-A or RAT-B

In these cases, the open phase occurs on either RAT-B or RAT-A when the transformer is supplying the Class 1E 4.16 kV bus associated with Division III. Scenarios with lightly and heavily loaded busses are analyzed. The Division I and II Class 1E busses supplied from the MPT are not significantly affected, with negative sequence voltages < 0.1 percent and voltages between 99 percent and 100 percent. The Division III Class 1E bus supplied by RAT-A or RAT-B will actuate on negative sequence voltage resulting in a transfer to the EDG. The open phase on RAT-A or RAT-B would alarm in the Main Control Room and the operator would switch to the transformer without the open phase. After transferring to an offsite source without an open phase, the EDG would then be secured.

Simulations are performed where the Class 1E 4.16 kV bus being supplied by the transformer with the open phase is lightly or heavily loaded. The automatic actions, operator actions and the ETAP results are shown in the following tables.

Generator Offline – Backfeeding via MPT Open Phase on RAT-A or RAT-B
Automatic Actions
Open Phase on the high voltage side of RAT-A or RAT-B (Phase A)
Open Phase alarms in Main Control Room
Division III Class 1E 4.16 kV bus experiences a negative sequence voltage > 4.5%
After 2.5 second time delay, the feeder breaker to the Division III bus is opened
Division III bus reaches UV setpoint
After a 3 second time delay, EDG on Division III starts
When the EDG reaches full speed, the Loss Of Off-site Power (LOOP) sequencer connects the appropriate loads to the EDG
Operator Actions
Based on the open phase alarm, operators start to implement their response procedure
When the open phase alarm is confirmed, the operators enter TS 3.8, Electrical Power Systems
The procedure guides operators to transfer the offsite power source to an unaffected source of offsite power
Once transfer is successful, the EDG is secured and TS 3.8 LCO is exited
Troubleshooting and maintenance take place on the transformer with the open phase

Generator Offline – Backfeeding via MPT Open Phase on RATs				
Case	7	8	9	10
Transformer with open phase	RAT-A	RAT-A	RAT-B	RAT-B
Loading of 4.16 kV bus affected by open phase	Heavy	Light	Heavy	Light
Div 1 Negative Sequence Voltage [%]	0.0	0.0	0.0	0.0
Div 1 Bus V_{AB} [%]	99.6	99.6	99.3	99.3
Div 1 Bus V_{BC} [%]	99.6	99.6	99.3	99.3
Div 1 Bus V_{CA} [%]	99.6	99.6	99.3	99.3
Div 2 Negative Sequence Voltage [%]	0.0	0.0	0.0	0.0
Div 2 Bus V_{AB} [%]	99.3	99.3	99.5	99.5
Div 2 Bus V_{BC} [%]	99.3	99.3	99.5	99.5
Div 2 Bus V_{CA} [%]	99.3	99.3	99.5	99.5
Div 3 Negative Sequence Voltage [%]	17.2	26.9	17.3	28.0
Div 3 Bus V_{AB} [%]	66.9	58.2	66.6	57.5
Div 3 Bus V_{BC} [%]	96.0	100.0	95.9	100.0
Div 3 Bus V_{CA} [%]	90.7	71.2	90.3	69.3

Summary of ETAP Simulations

For at-power scenarios with the generator on-line, an open phase on the high side of the MPT or a RAT that is feeding a Class 1E 4.16 kV bus(es) will result in an actuation of the negative sequence voltage relays on the bus that is being fed and a transfer of the bus or busses to the EDG.

For scenarios where the generator is offline and back feeding from offsite via the MPT, an open phase on the high side of the MPT will not result in an actuation because the negative sequence voltages on all three Class 1E 4.16 kV busses remain less than the setpoint; the detection and alarm scheme will provide indication to the operators that an open phase condition exists and the operators will follow the procedures to disconnect the faulted power source from the plant's distribution system. Following this manual action, the safety bus will be transferred to another power source. If the open phase occurs on RAT-A or RAT-B while feeding a Class 1E 4.16 kV bus, actuation will occur on the Class 1E 4.16 kV bus. The Class 1E 4.16 kV busses fed by the MPT are not significantly affected.

There are no scenarios that rely on operator action to protect the Class 1E 4.16 kV busses from adverse negative sequence voltages. The operators will follow their procedures to address the open phase alarm and ensure that an OPERABLE offsite power supply is restored in a timely manner. It is important to note that ETAP can't simulate the loss of two phases. The ETAP simulations demonstrate that the negative sequence voltage relays will provide protection for the Class 1E 4.16 kV busses and ensure their availability in all plant modes.

Following the NINA's presentation of the simulations, the staff had the following observation:

1. The staff recommended to NINA to submit a summary of all the simulations presented to the staff during the audit within the RAI response to RAI 08.02-25 and RAI 08.02-26. This would provide documentation that NINA had studied the worst case scenarios that could affect the function of the safety related buses following an open phase event.

The information audited verified that the responses RAI 08.02-25 and RAI 08.02-26 were supported by analysis and simulations representing various scenarios were the STP, Units 3 and 4, would undergo following an open phase event.

<u>Document 1: STP-EC-14001, Revision 1, "Negative Sequence Relay Setting Calculation"</u>

Document 1 contains the STP-EC-14001, Revision 1, and "Negative Sequence Relay Setting Calculation," developed by DP Engineering Ltd., Co. Along with this calculation, NINA presented to the staff an actual model of the Negative Sequence Voltage Relay, or Phase Unbalance Relay. The model presented was an Asea Brown Boveri (ABB) Circuit Shield Type 60Q, "Phase Unbalance Relay," which is an analog relay. The staff also reviewed the relay specifications stated in ABB Descriptive Bulletin 41-238S, and the relay instructions stated in ABB Informational Bulletin (IB) 7.4.1.7-3, "Instructions, Phase Unbalance Relay." The ABB Circuit Shield Type 60Q relay includes a built-in harmonic filter that allows the relay to operate properly even if the voltage waveform is poor.

NINA also discussed the calculation of the expected nominal setpoint and the expected nominal time delay. These values are expected nominal values since the final design of the system has not been completed and final procurement information for the Negative Sequence Relays is not available yet. The expected nominal setpoint is 4.5 percent (design limit is 5 percent) and the expected nominal time delay is 2.5 seconds (design limit is 3 seconds). The time delay is selected to be short enough to ensure that motors do not trip on overcurrent should a running motor stall or if one tries to start and long enough to prevent inadvertent actuations due to normal bus disturbances. If the negative sequence voltage remains above the expected

nominal setpoint on 2 out of 3 sensors for 2.5 seconds, actuation occurs. The relays that will be used on STP, Units 3 and 4, will have an expected nominal negative sequence voltage setpoint of 4.5 percent (with a design limit of 5 percent).

The staff audited the calculation and the staff had the following observation:

1. The staff recommended to NINA to submit a description, operation, and setpoints of the Negative Sequence Voltage Relay within the RAI response to RAI 08.02-25 and RAI 08.02-26. This would provide documentation of the automatic actuation component of NINA's proposed solution at the Class 1E safety buses that would isolate the safety buses from the unbalanced power system upon the onset of an open phase condition.

The information audited verified that the responses RAI 08.02-25 and RAI 08.02-26 were supported by calculations and other documentation to support the use of the Negative Sequence Relay as the automatic actuation mechanism component of the open phase solution provided by NINA.

5.0 CONCLUSION

In summary, the ETAP 345 kV Transformer Open Phase Study simulations, and the Negative Sequence Relay Setting Calculation along with other supporting documentation was audited by the NRC staff. Based on the review of the simulations, calculations, and additional information provided by the applicant the NRC staff confirmed that the STP combined license application addresses the questions from the staff in regards to RAI 08.02-25 and RAI 08.02-26. The information audited verified that the answers to these RAIs are supported by the analysis and other supporting documentation developed by Nuclear Innovation North America, LLC. (NINA) to address the issues described in Bulletin 2012-01.

6.0 REFERENCES

1. Bulletin 2012-01, "Design Vulnerability in Electric Power System."

2. NRO Office Instruction NRO-REG-108 (Revision 0), "Regulatory Audits."

3. Calculation STP-EC-14001, Revision 1, "Negative Sequence Relay Setting Calculation," by DP Engineering.

4. ABB Descriptive Bulletin 41-238S, "Circuit Shield Type 60Q Phase Unbalance Relay."

5. ABB Informational Bulletin (IB) 7.4.1.7-3, "Instructions, Phase Unbalance Relay."

6. Standard Review Plan Section 8.1, "Electric Power – Introduction."

7. Standard Review Plan Section 8.2, "Offsite Power Systems."

8. Standard Review Plan Section 8.3.1, "AC Power Systems (Onsite)."